International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 3, March-April 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Composition Optimization of Extrudable Mortar for 3D Concrete Printing

Abhishek Kumar Krishnavansham[1], Dr. Abhay Kumar Jha[2], Barun Kumar[3]
[1]Research Scholar, [2]Associate Professor, [3]Assistant Professor,
[1,2,3]Department of Civil Engineering, Lakshmi Narain College of Technology (LNCT), Bhopal, Madhya Pradesh, India

ABSTRACT
Furthermore, this Paper workis focused on the optimization of the3Dprintingmixcomprising micro silica fume and poly propylene as admixture. Additive manufacturing (AM),also known as 3D printing, is the most promising new solution in the construction industry for overcoming various challenges in the traditional construction process. 3D printing, also known as additive manufacturing, is a layer-by-layer deposition method for converting a computer model into a physical structure, solid object, or component using a 3D printer. To construct a physical 3D item, a digital model (CAD model) is used (Bogue et al. 2013). The result is a solid 3D object.

KEYWORDS: *printing mix, digital model, computer model, construction, traditional*

How to cite this paper: Abhishek Kumar Krishnavansham | Dr. Abhay Kumar Jha | Barun Kumar "Composition Optimization of Extrudable Mortar for 3D Concrete Printing" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-3, April 2022, pp.699-703, URL: www.ijtsrd.com/papers/ijtsrd49587.pdf

IJTSRD49587

INTRODUCTION
Any country's economic development is largely dependent on the Construction industry. Traditional construction, on the other hand, has a number of issues, the most serious of which are speed and labour efficiency. There are numerous obstacles that must be overcome in order to keep the construction site under control, and physical labour participation causes a number of health-related issues for workers [OSHA US department]. Because construction projects take a long time to complete, the construction industry's biggest stumbling block is the slow pace at which projects are complete. Environmental pollution and carbon emissions are rapidly increasing due to construction industry.

3DCP is a low-labor-cost approach, and if it is employed in large-scale constructions, it will be far more cost-effective than traditional construction. 3D printing gives the a lot of leeway in terms of creating complicated geometrical shapes and enables for complete design customization to the designer. The typical construction approach produces a large amount of garbage, which has a negative impact on the environment and human health. In most cases, 3D concrete printing simply requires the material to construct a structure. As a result, this approach produces very little trash, it has very minimal negative environmental effects and so minimizes carbon emissions.

Additive manufacturing (AM) or 3D printing in the construction industry is the most promising modern way to overcome many obstacles in the traditional way of construction.3D printing or Additive manufacturing is the process of the layer-by-layer deposition as shown in for purpose of converting a designed digital model into the real structure, solid model, or component with the help of a 3D printer i.e. a solid 3D object is formed from a digital model (CAD model) (Bogue et al. 2013). In this method solid 3D object is prepared by placing a layer over the layer. This 3D printing or AM commits to significant achievements in construction such as waste minimization, mass customization, design freedom,

and the capability to build a complex structure, which is not generally convenient to construct with traditional construction techniques. In the construction field Additive manufacturing (AM) or 3D printing is the most promising new approach to overcome several hurdles in the traditional construction process. 3D printing, also known as additive manufacturing, is a layer-by-layer deposition method that uses a 3D printer to convert a specified digital model into a physical structure, solid object, or component. i.e. a digital model (CAD model) is used to create a solid 3D object (Bogue et al. 2013). A solid 3D object is created using this method by layering a layer over another layer. Waste reduction, mass customization, design flexibility, and the capability to make a complex structure which is not possible to construct with traditional construction techniques.

Furthermore, this dissertation work is focused on the optimization of the 3D printing mix comprising micro silica fume and poly propylene as admixture. Additive manufacturing (AM), also known as 3D printing, is the most promising new solution in the construction industry for overcoming various challenges in the traditional construction process. 3D printing, also known as additive manufacturing, is a layer-by-layer deposition method for converting a computer model into a physical structure, solid object, or component using a 3D printer. To construct a physical 3D item, a digital model (CAD model) is used (Bogue et al. 2013). The result is a solid 3D object.

Research Objective:

- To design the mix for the suitability of 3D printing.
- Assessment of the mix properties for fresh and hardened properties and optimizing the mix for pump ability and extrude ability
- Utilization of silica fume and polypropylene fibre in mix for achieving higher strength and lower cracks

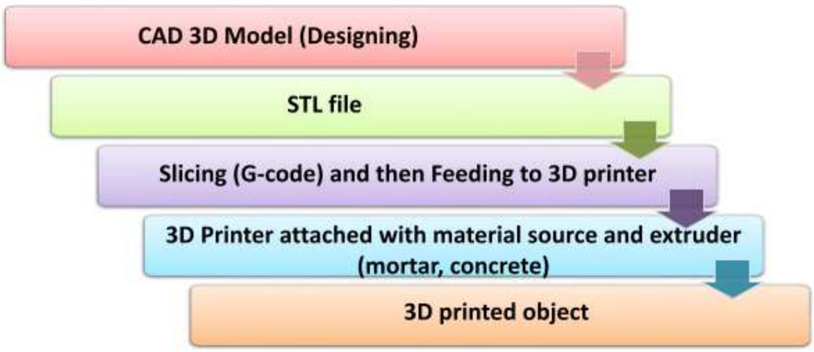

Figure 1: 3D Printing Process

Literature review

Tay and Tan (2019)

In this work for the evaluation of Pump ability and Build ability of the mixture an investigation on slump and slump flow value has been done, additionally, a new parameter is known as Pump ability index (ratio of the flow rate of concrete to that of water at pumping speed of 2890rpm) is introduced to check whether the mixture is pump able or not. Furthermore, this work also aims to map out the regions of printable and nonprintable to check whether the mortar mix can be used for 3DCP. In this work, it was found that compared to replacement of Silica fumes and fly-ash, water to binder ratio and sand to binder ratio play a much bigger role in controlling slump and slump flow values. It was also found that the surface quality of 3D printed specimens increases with an increase in a slump and slump flow value and printability index. With slump value between 4mm-8, mm of a mortar mix and Flow value in between 150mm-190mm gives a smooth surface and high build ability.

Zhang et al. (2019)

On the basis of flow ability of cement paste and optimum aggregate content this research work develops a 3D printable concrete. The methodology involves 3 types of tests- (1) Flow ability test

– In this test after making the mix it is filled into a truncated cone which is then lifted vertically and flow ability is measured. (2) build ability test – In this test a cylindrical mould is filled with 3D printable concrete in 3 layers and each layer is compacted by roding 15 times in each layer than cylindrical mould is lifted and build ability is measured, (3) Rheological test – in Brookfield rheometer at a constant rotating speed of 0.2/s for the duration of 2 minutes rheology test is performed. The conclusions that can be drawn are- There is a linear relationship exists between the flow ability of cement paste and optimum aggregate content for a printable mortar, the relationship is independent of w/b ratio and choice of raw material for binder. The thickness of excess paste coating on the mortar has a significant effect on the rheological properties of the mortar. Mortar with the same excess

paste thickness possess the same rheological behavior as well as the same printability.

Allouzi et al. (2020)
Examine the comparative study between 3D printing and conventional construction on the point of material cost. This research article also targets to the considerate of procedure of 3-D printing, it's mechanism as well as impact through environmental, economic, and structural consideration is accomplished on the upcoming of construction. In this article, Rawan Allouzi compares the traditional construction info of Ras Alain versatile Hall (Jordan) in addition to predictable information if this similar structure would have been built with using 3DCP. The construction cost of Ras Alain Hall by using 3DCP is equaled to 8,872.5 JD (Jordan Dollar) deprived of the insulation work and stone cladding, and construction amount of the same hall by using traditional construction method is 57,947 JD if insulation work and stone clad26,287 JD. So by this evidence of Rawan Allouzi, the concrete cost of Ras Alain Hall based on 3DCP is 8,872.5 JD is fewer than the traditional cost of construction which around 26,287 JD. The study concludes 3DCP diminishes 65% of traditional material costs. The labor costs, equipment cost, and construction time is not considered in this study meanwhile these factors depend on the speed and essential size of a 3-D concrete printer.

26,287 JD. So by this evidence of Rawan Allouzi, the concrete cost of Ras Alain Hall based on 3DCP is 8,872.5 JD is fewer than the traditional cost of construction which around 26,287 JD. The study concludes 3DCP diminishes 65% of traditional material costs. The labor costs, equipment cost, and construction time is not considered in this study meanwhile these factors depend on the speed and essential size of a 3-D concrete printer.

Arunothayan et al. (2020)
This paper presents the systematic development and performance characterization of a non- proprietary 3D-printable ultra-high-performance fiber-reinforced concrete (UHPFRC). Several fresh and hardened state properties of the 3D-printable UHPFRC matrix (without fiber) and composite (with 2% volume fraction of steel fibers) were evaluated and compared to that of conventionally mold-cast UHPFRC. Additionally, the effects of test direction on the compressive strength and modulus of rupture of the printed UHPFRC were investigated. The fresh properties of the UHPFRC developed in this study satisfied the criteria for extrudability, buildability, and shape-retention-ability, which are relevant for ensuring printability. The printed UHPFRC exhibited superior flexural performance to the mold-cast UHPFRC due to alignment of the short fibers in the printing direction. The high compressive and Flexural strength, along with the deflection-hardening behavior, of the developed UHPFRC can enable the production of thin 3D- printed components with significant reduction or complete elimination of conventional.

Jun Ho Jo et al. (2020)
Present a formation of a prototype 3DCP printer aimed at concrete construction at lab scale size along with the assessment of Cementitious materials in a laboratory. Jun Ho Jo initially picked Cartesian FDM (fused deposition modeling) sort of 3-D printer for laboratory testing through a linear servo motor, each and every individually functioning motor augments the quality of printing. Two mixes are prepared for the testing, the composition of mixes are as follows – first mix, Cement 2000 gram in addition to sand 3500 gram, water 615 gram along with PVA 2 gram and W/C is around 0.308, having Compressive strength is 60.4 MPa; second mix, Cement 5000 gram in addition to sand 8750 gram, water 1550 gram along with PVA 5 gram and W/C is around 0.31, having Compressive strength is 62 MPa. For proper extracting and layering of cementitious mix from the 3-D printer for the testing of materials, a slump flow range and W/C ratio of 190mm- 200mm and 0.30-0.32, respectively. To avoid clogging or bleeding during 3-D printing, 0.4 quantity of sand having a maximum size is 0.7 mm is found to suitable in cement formed mortar mix during testing. Further 0.1 % PVA fibers are used to diminish the shrinkage cracking in addition to enhancing the superiority of printing.

Khan (2020)
This is a review work done by Khan which aims at reviewing suitable concrete 3D printed mix. From the study of different researchers following observations are drawn- There is a formation of Lubrication layer in the pipe due to segregation of concrete while pumping the mix because of that less pumping pressure is required. The flow ability of concrete is governed by particle size distributions of binder and sand grains. The suitable range of size of fine aggregate is in between 1mm – 2mm. For a mix having low yield stress and dynamic viscosity are helpful in pumpabilty of concrete nut for that same mix there is a problem. Observed in achieving Build ability. There is higher yield stress is observed for a mix having continuous gradation of material. Printable ranges of Plastic viscosity varies between 16.65 to 33.1 Pa-s and Static yield stress within 1.87 to 3.35 kPa.

METHODOLOGY

Portland Pozzolana Cement, fly-ash, micro silica fume, polypropylene fiber and sand was stocked or reserved at moisture free location or lab. These material are used in for finding the optimum mix which is suitable for 3D printing.

Sand/Binder = 1.0

Water/Binder = 0.45

Fly-ash = variation with 0%,5%, 10%, 15%, 20%

Silica fume /Binder = variation with 0%, 5% ,10%

PPF variation with = 0%, 0.2%, 0.4%, 0.6%, 0.8 %

Table 1: Chemical Characteristics of fly ash

Characteristics	Result obtained	Requirement as per IS 3812 (Table 2)
SiO2	56.42	Min. 35
SiO2+Al2O2 + Fe2O3 (%)	92.55	Min. 70
MgO (%)	0.44	Max. 5
SO3 (%)	0.13	Max. 3

CONCLUSION

1. The study concluded that 3D concrete printing is the process of layer-by-layer deposition for purpose of converting a designed digital model (CAD file → Mesh file → .stl file → 3D printed component) into the desired structure.
2. The results reveal that incorporation of fly ash in cement mortar improves the workability significantly. Compressive strength increased with curing age for all fly ash replacements. Irrespective of fly ash % the compressive strength decreases at early age when compared to reference mortar. However, at later curing age mortars made with 5%, 10%, 15%, 20% shows higher strength than reference mortar. Maximum efficiency of mortar mix is found at 10% fly ash content.
3. Silica Fume is exceptionally fine, the micro filling effect of silica fume significantly improves the binding of mix and provides more initial strength compared to conventional mortar and prevent the micro cracks. The Optimum Replacement level of cement by silica fume is found to be 5% by weight. There is a significant improvement in the compressive strength of concrete using silica fume at both 7 and 28 days as compare to the referral mortar and reduce the Workability of mix. Beyond optimum levsssel of silica fume decreases the strength.
4. The use of polypropylene fiber affects the workability of fiber reinforcement mortars, polypropylene fibers reduce the workability of mortar mixes and compressive strength of mortar mix increases with increase the fiber content from 0.2%-0.6% and further increase the fiber content it reduce strength of mortar mix. Fiber reduce the cracks and it does not show the cracks on surface of sample after the failure. The Optimum level of polypropylene fiber is 0.6% by weight of binder.

REFERENCES

[1] Allouzi, R., Al-Azhari, W., & Allouzi, R. (2020). Conventional Construction and 3D Printing: A Comparison Study on Material Cost in Jordan. Journal of Engineering, 2020.

[2] Azimi-Pour, M., Eskandari-Naddaf, H., & Pakzad, A. (2020). Linear and non-linear SVM prediction for fresh properties and compressive strength of high volume fly ash self-compacting concrete. Construction and Building Materials, 230, 117021.

[3] Bandyopadhyay, A., & Bose, S. (Eds.). (2019). Additive manufacturing. CRC press.

[4] Baz, B., Remond, S., & Aouad, G. (2020). Influence of the mix composition on the thixotropy of 3D printable mortars. Magazine of Concrete Research, 1-13.

[5] Behnood, A., & Golafshani, E. M. (2018). Predicting the compressive strength of silica fume concrete using hybrid artificial neural network with multi-objective grey wolves. Journal of cleaner production, 202, 54-64.

[6] Bogue, Robert. "3D printing: the dawn of a new era in manufacturing." Assembly Automation (2013).

[7] Bos, F., Wolfs, R., Ahmed, Z., & Salet, T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing. Virtual and Physical Prototyping, 11(3), 209-225.

[8] Craveiro, F., Nazarian, S., Bartolo, H., Bartolo, P. J., & Duarte, J. P. (2020). An automated system for 3D printing functionally graded concrete-based materials. Additive Manufacturing, 101146.

[9] Craveiroa, Flávio, et al. "Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0." sustainable development 4 (2019): 6.

[10] Eskandari-Naddaf, H., & Kazemi, R. (2018). Experimental evaluation of the effect of mix design ratios on compressive strength of

cement mortars containing cement strength class 42.5 and 52.5 MPa. Procedia Manufacturing, 22, 392-398.

[11] Hanumesh, B. M., Varun, B. K., & Harish, B. A. (2015). The mechanical properties of concrete incorporating silica fume as partial replacement of cement. International Journal of Emerging Technology and Advanced Engineering, 5(9), 270.

[12] He, X., & Shi, X. (2008). Chloride permeability and microstructure of Portland cement mortars incorporating nanomaterials. Transportation Research Record, 2070(1), 13-21.

[13] Hossain, M., Zhumabekova, A., Paul, S. C., & Kim, J. R. (2020). A Review of 3D Printing in Construction and its Impact on the Labor Market. Sustainability, 12(20), 8492.

[14] Ji, G., Ding, T., Xiao, J., Du, S., Li, J., & Duan, Z. (2019). A 3D Printed Ready- Mixed Concrete Power Distribution Substation: Materials and Construction Technology. Materials, 12(9), 1540.

[15] Jo, J. H., Jo, B. W., Cho, W., & Kim, J. H. (2020). Development of a 3D Printer for Concrete Structures: Laboratory Testing of Cementitious Materials. International Journal of Concrete Structures and Materials, 14(1), 1-11.